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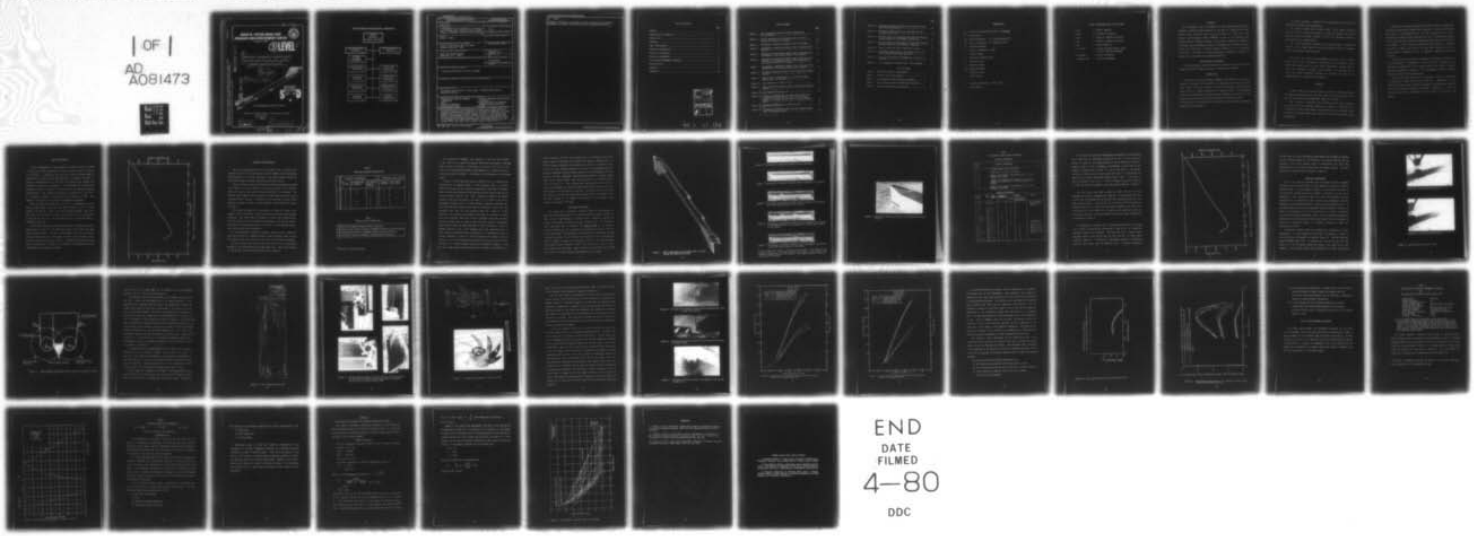

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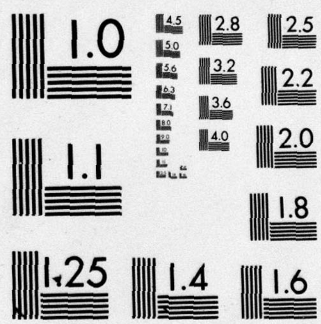

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INVESTIGATION OF THE FEASIBILITY OF PROPELLER LARGE SURFACE EFFECT SHIPS WITH WIDELY SPACED, PARTIALLY SUBMERGED, SUPERCAVITATING PROPELLERS

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

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INVESTIGATION OF THE FEASIBILITY OF PROPELLING LARGE SURFACE EFFECT SHIPS WITH WIDELY SPACED, PARTIALLY SUBMERGED, SUPERCAVITATING PROPELLERS.

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BY

ROBERT F. RODDY

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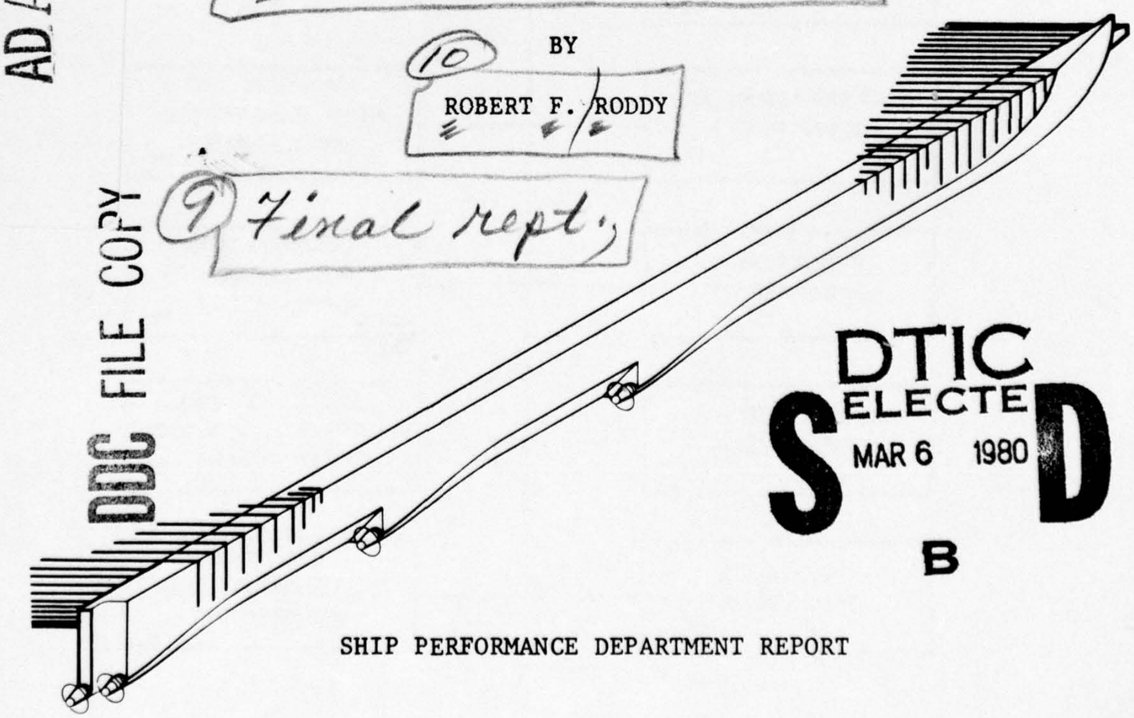

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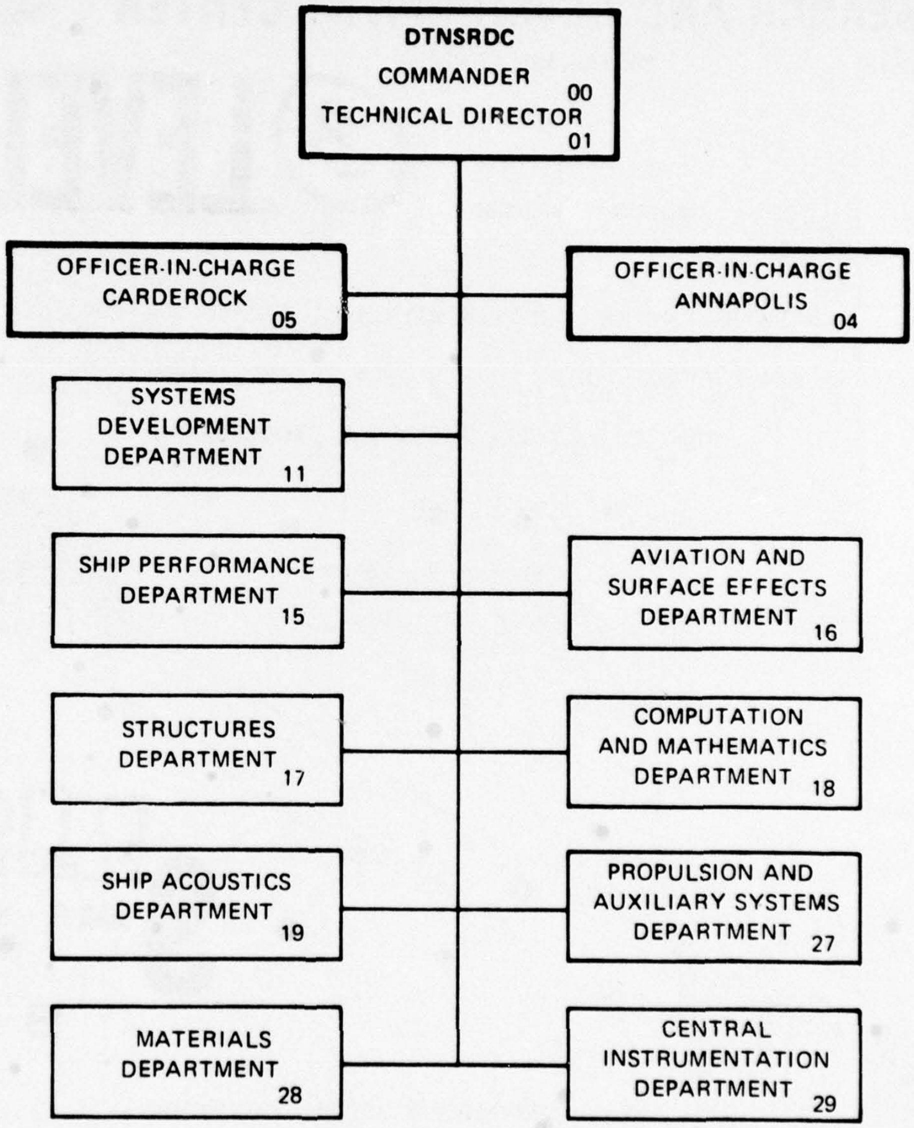

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An investigation into the feasibility of using widely spaced partially submerged, supercavitating propellers as the means of propulsion for large surface effect ships was carried out at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) as part of the Advanced Naval Vehicles Concept Evaluation Program. This method of propulsion is shown to be feasible and a performance estimate is developed for an 8,000 ton surface effect ship (SES) with a cushion length to beam ratio of 5.

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Necessary information is presented for making preliminary performance estimates for similar craft using partially submerged propellers.

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NOMENCLATURE

A_S	Area of the propeller disc that is submerged
b	Cushion beam
C_P	Power coefficient-- $(2\pi Q n)/((\rho/2)A_S V^3)$
C_T	Thrust coefficient-- $(T)/((\rho/2) A_S V^2)$
D	Propeller diameter
J	Advance coefficient-- $V/(nD)$
l	Cushion length
n	Propeller revolution rate
P	Propeller pitch
Q	Propeller torque
SHP	*Shaft horsepower*
T	Propeller thrust
V	Ship velocity
η	propeller efficiency-- $TV/(2\pi Qn)$
ρ	water density

METRIC CONVERSIONS USED IN THIS REPORT

1 foot	=	0.3048 m (meters)
1 inch	=	25.40 mm (millimeters)
1 knot	=	0.5144 m/s (meters per second)
1 fps	=	0.3048 m/s (meters per second)
1 Lbf	=	4.448 N (newtons)
1 ton (2240)	=	1.016 m ton (metric tons), where 1 m ton = 1000 kg (kilograms)
1 horsepower	=	0.746 kW (kilowatts)
1 nautical mile	=	1.852 km (kilometers)

ABSTRACT

An investigation into the feasibility of using widely spaced partially submerged, supercavitating propellers as the means of propulsion for large surface effect ships was carried out at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) as part of the Advanced Naval Vehicles Concept Evaluation Program. This method of propulsion is shown to be feasible and a performance estimate is developed for an 8,000 ton surface effect ship (SES) with a cushion length to beam ratio of 5. Necessary information is presented for making preliminary performance estimates for similar craft using partially submerged propellers.

ADMINISTRATIVE INFORMATION

This investigation was authorized and funded by Naval Sea systems Command, Code PMS 304 under work units 1-1102-003 and 1-1102-005.

INTRODUCTION

The Naval Sea Systems Command (NAVSEA), Code PMS 304, initiated a program to determine the feasibility of propelling large surface effects ships (LSES) with widely spaced, partially submerged, supercavitating propel lers as a viable alternative to a waterjet system. The parameters relative to propulsion performance were addressed, the areas of ship motions, structures, and machinery constraints were not part of this investigation. The rationale for this work is that partially submerged propellers should produce:

(1) Higher efficiency - possibly 10 to 25 percentage points higher than the waterjet systems now being proposed.

(2) Greater payload and/or greater range - with higher efficiency there will be less required horsepower and less fuel required for a given mission (permitting greater payload), or with the equivalent amount of fuel there can be a longer mission.

(3) Less performance degradation from battle damage or mechanical failure - with a larger number of identical propulsion plants the independence of the plants has been maximized.

This report will discuss the development of the basic craft configuration used in this investigation, development of the propulsor configuration that should give the best overall performance, methods used to verify the performance estimates, data necessary for producing preliminary point design performance estimates for arbitrary SES designs, and recommendations for necessary future research.

PROCEDURE

A surface effect ship form that would be used as a vehicle was defined and drag characteristics over the speed range were then supplied by the Aviation and Surface Effects Department (ASED) of the Center.

Next a propeller optimization was performed for the craft propelled by a single partially submerged propeller per sidewall. Predictably such a propeller is quite large. However, the performance of this propeller would be used as a benchmark against which any gain, or loss, in performance could be measured.

Following this baseline design study various possible configurations with multi-propellers per sidewall were considered. Several were discarded for reasons to be discussed later. The final configuration was a four-propeller-per sidewall system consisting of a set of overlapping propellers at the transom and two inclined and yawed propellers along the after half of the sidewall. A short series of experiments were performed to determine the possible change in the drag of the craft when configured for such a multi-propeller installation since no expedient analytical method was available.

Calculations were then made to determine the predicted performance of the multi-propeller configuration. Since no data was available for an overlapping configuration at the transom, another short series of experiments were performed to determine if the overlapping, partially submerged propellers would perform satisfactorily.

With the data thus obtained it was possible to show the feasibility of propelling a large surface effect ship with a combination of overlapping and widely spaced, partially submerged, supercavitating propellers and to then perform preliminary performance estimates for a LSES. The various steps will be discussed in further detail in the body of the report.

CRAFT CONFIGURATION

At the commencement of this program the sponsor selected an 8,000 ton aircraft carrier type surface effects ship operating at 60 knots in a sea state 3. Tentatively this craft was to have a cushion length to beam ratio of 6.5 and a drag of 600,000 pounds (2.669 MN) at 60 knots. A propeller optimization for a craft with one propeller per sidewall was performed by using data of reference 1. Its performance was to be used as a benchmark from which to measure the performance of the multiple propeller configurations. This optimization resulted in a propeller 31.2 feet (9.51 m) in diameter turning at 133 RPM and with efficiency of 0.702. (See Appendix A for details of the propeller optimization procedures).

While the drag characteristics of an l/b = 6.5 configuration are very good at speeds equal to and less than about 60 knots, an l/b = 5.0 was agreed to by PMS 304 to make a more severe design problem. This craft would have a cushion length of about 464 feet (141.2 m) and a cushion beam of about 93 feet (28.3 m). The drag characteristics furnished by ASED are presented in Figure 1.

The 60 knots design speed was specified as about the highest practical design speed for this l/b; for speeds much higher than 60 knots the drag penalty becomes severe. It should be noted though, that this ship can be operated economically over a wide range of speeds due to its smooth, relatively low drag characteristics (Figure 1). However some variations in drag would be expected due to changes in the sidewall form necessitated by the installation of the propeller shafting.

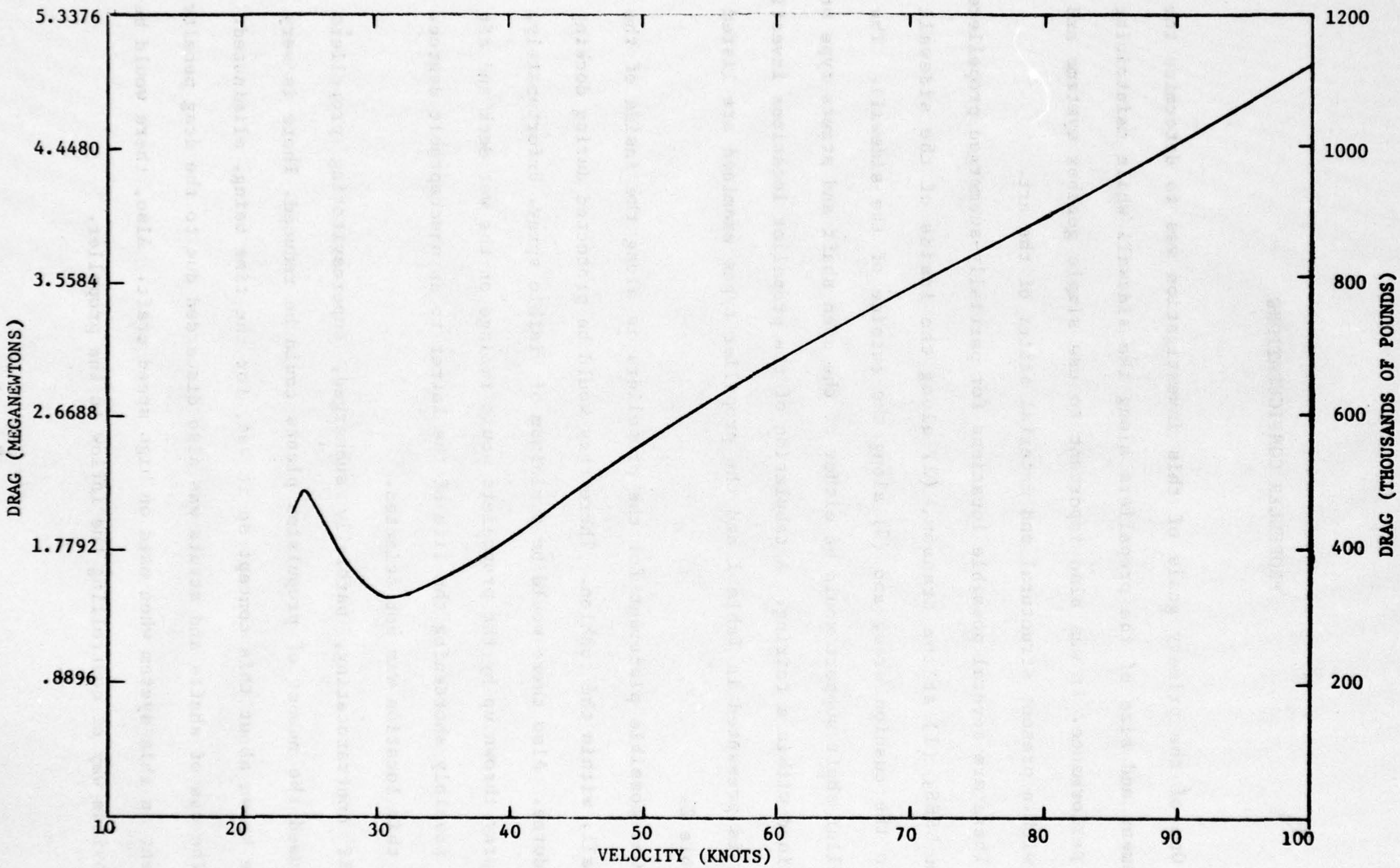


FIGURE 1 - Drag of Baseline 8,000 Ton Surface Effects Ship In a Sea State 3

PROPELLER CONFIGURATIONS

One of the primary goals of this investigation was to determine the placement and size of the propellers along the sidewall while maintaining good performance. It was also important to use simple gearbox systems and stay within present structural and material states of the art.

There are several possible locations for partially-submerged propellers on an LSES; (1) at the transom, (2) along the inside of the sidewall within the cushion area, and (3) along the outside of the sidewall. The propeller shaft support would be either of the open shaft and struts type or contained within a fairing. A tabulation of the propeller locations investigated is presented in Table 1 and the propeller types examined are listed in Table 2.

One possible placement for the propellers is along the inside of the sidewall, within the cushion. There they would be protected during docking procedures. Also there would be a minimum of visible spray. Unfortunately, the spray thrown up by the propellers would impinge on the wet deck and aft seals possibly shortening the life of the latter to an unacceptable degree. Hence this location was not selected.

If contrarotating, partially submerged, supercavitating propellers were used the number of propulsion plants could be reduced. There is very little known about this concept so it was, for the time being, eliminated.

The use of shafts and struts was also discarded due to the drag penalty inherent in this system when used on high speed craft. Also, there would be no obvious way of controlling the inflow to the propeller.

TABLE 1

PROPELLER LOCATIONS INVESTIGATED

	LOCATION OF PROPELLERS			PROPELLER SHAFT SUPPORT	
	AT TRANSOM	ON INSIDE WALL OF SIDEWALL	ON OUTSIDE WALL OF SIDEWALL	SIDEWALL FAIRINGS	OPEN SHAFTS AND STRUTS
1	X	X		X	
2	X	X			X
3	X		X	X	
4	X		X		X
5	X	X	X	X	
6	X	X	X		X
7*	X				

TABLE 2

PROPELLER TYPES INVESTIGATED

1	PARTIALLY SUBMERGED SUPERCAVITATING PROPELLERS
2	TANDEM (WIDELY SPACED) PARTIALLY SUBMERGED SUPERCAVITATING PROPELLERS
3	CONTRAROTATING PARTIALLY SUBMERGED SUPERCAVITATING PROPELLERS
4	OVERLAPPING PARTIALLY SUBMERGED SUPERCAVITATING PROPELLERS

* Used Only as a Baseline Design

The propulsion arrangement that appeared to have the most promise at this time is one in which the propeller shafts would be housed in fairings. These fairings are similar to those used at the stern of the craft of the various l/b experiments performed by ASED (Reference 2), modified to have a very short parallel afterbody. (The details of the fairing will be discussed later).

The size of the propellers along the sidehull are, to a large extent, determined by the sidewall width. If the propeller shaft is to remain within the fairing then the propeller radius must be less than the sidewall width; otherwise the propeller would protrude into the cushion area and the cushion pressure could be lost. From a resistance viewpoint the maximum sidewall width was specified to be about 12 to 14 feet (3.66-4.27m). Preliminary estimates for 12′ (3.66m) diameter propellers indicated that three propellers per sidewall could yield an efficiency of about 62%, four propellers about 65%, and five propellers about 67%. Using 14′ (4.27m) propellers two propellers per sidewall could yield an efficiency of about 60%, three propellers about 66%, and four propellers about 68%. Reliable full-scale predictions can only be made from model propeller performance characteristics when the model propeller is fully ventilated. Since the maximum efficiency that can be obtained with fully ventilated flow is about 64-65% (for Propeller 4281, see Figure A-1) a configuration of four 12′ (3.66m) propellers or three 14′ (4.27m) propellers per sidewall would be selected. All of the above predictions were made using the drag of a LSES with about a 12′ (3.66m) sidewall beam and one fairing per sidewall. It was felt that larger drag corrections would have to be made to the LSES with 14′

(4.27m) sidewalls and that any possible gain in performance from using larger diameter propellers would probably be negated, therefore four 12′ (3.66m) diameter propellers per sidewall were selected. The best configuration for these propellers appeared to be a pair of overlapping, inclined, partially submerged, supercavitating propellers at the transom and two other inclined, partially submerged, supercavitating propellers running through yawed shafts equally spaced along the after half of the sidewall (Front cover and Figure 2). This configuration would minimize the number of fairings and maximize the distance between them without placing any propulsion engines in the bow quarter of the ship. It is also felt that the added drag caused by the three fairings along the after half of the sidewall would be offset somewhat by the dynamic lift produced by the fairings thereby reducing the required lift power.

RESISTANCE EXPERIMENTS

Since there was no expedient analytical method for determining the added and interference drag for the proposed multiple sidewall fairings, a short series of experiments was conducted with a simplified sidehull and several combinations of sidewall fairings, (Figures 3-8). The purpose of these experiments was to determine the change in drag due to different fairing configurations and to determine the interference drag as a function of fairing spacing. The experiments were performed at scaled speeds (Froude scaling) from about 30 to 100 knots and covered the five configurations shown in Figures 3 through 7 and tabulated in Table 3. The model was fixed at a scaled transom immersion of about 13.9 feet (4.24 m) and at a stern down trim of about one degree. These conditions were obtained from the ASED for the l/b = 5.0 craft running at approximately design speed.

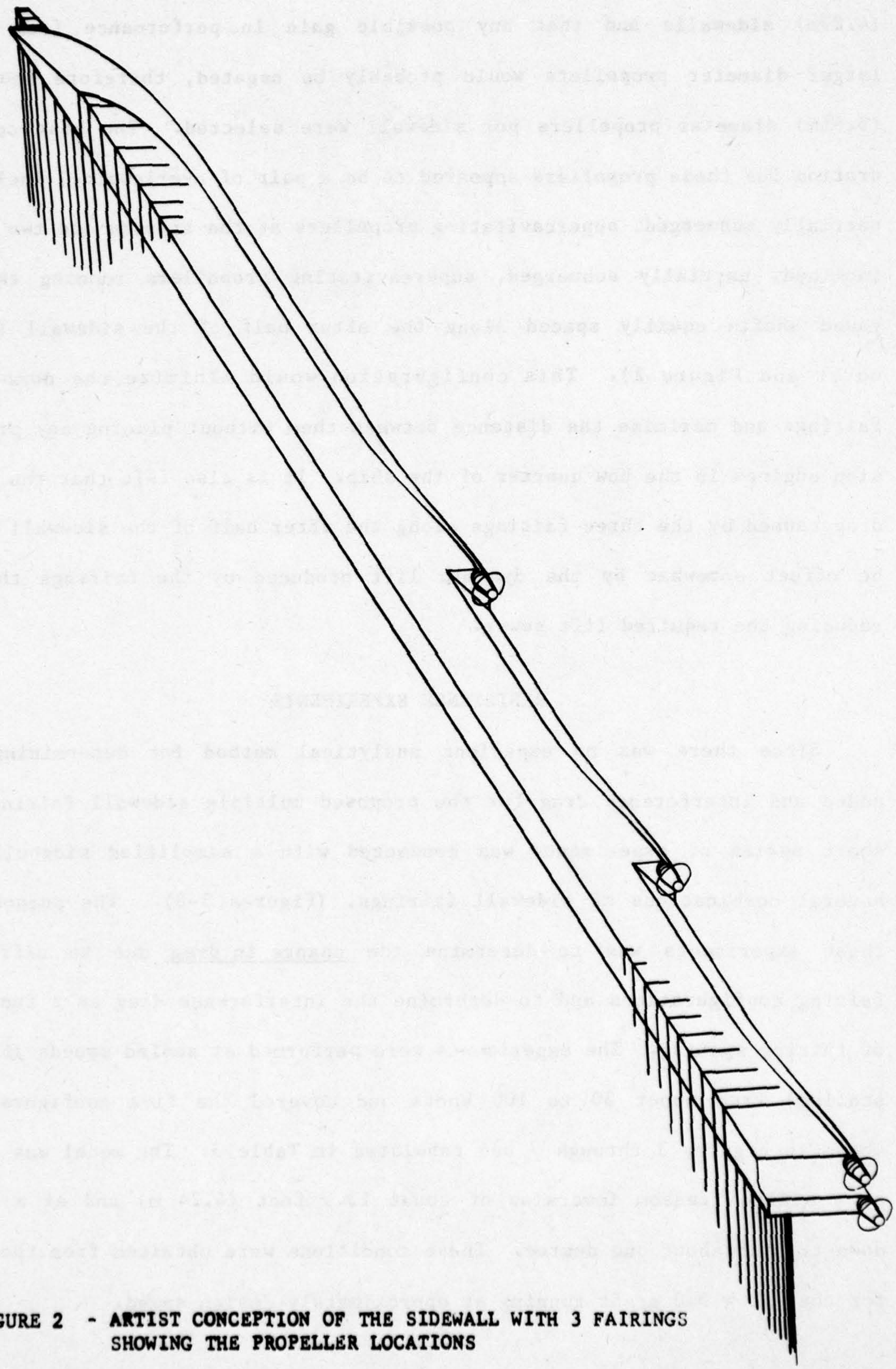


FIGURE 2 - ARTIST CONCEPTION OF THE SIDEWALL WITH 3 FAIRINGS SHOWING THE PROPELLER LOCATIONS

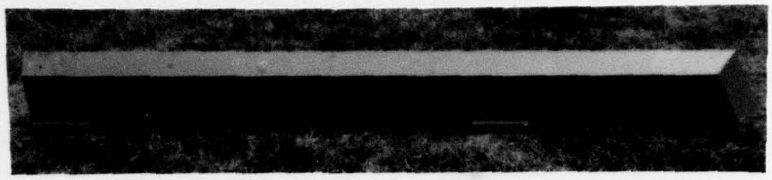


FIGURE 3* - Photograph of Simplified Sidewall With No Fairings

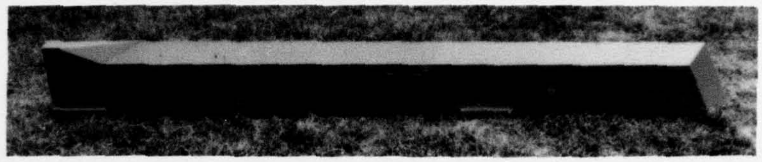


FIGURE 4* - Photograph of Simplified Sidewall With a Fairing at the Transom

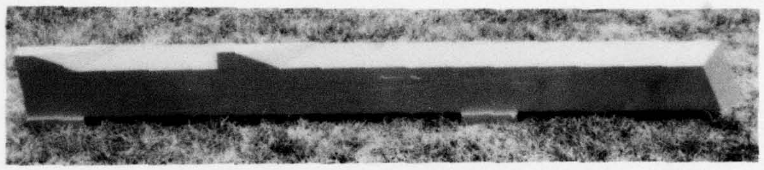


FIGURE 5* - Photograph of Simplified Sidewall With a Fairing at the Transom and at 25% Length Forward of the Transom

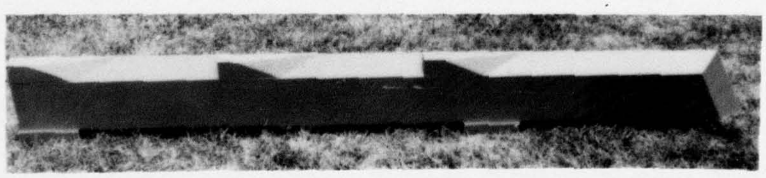


FIGURE 6* - Photograph of Simplified Sidewall With a Fairing at the Transom, at 25% Length Forward of the Transom and at 50% Length Forward of the Transom

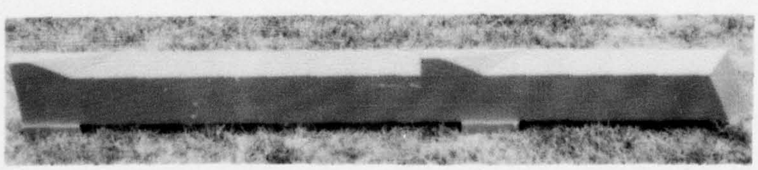


FIGURE 7* - Photograph of Simplified Sidewall With a Fairing at the Transom and at 50% Length Forward of the Transom

*In these figures the model is upsidedown with the bow to the right and the transom on the left. The darker protion of the model in each figure is the vertical outside surface of the sidewall; the lighter portion is the 45° surface of the sidewall.

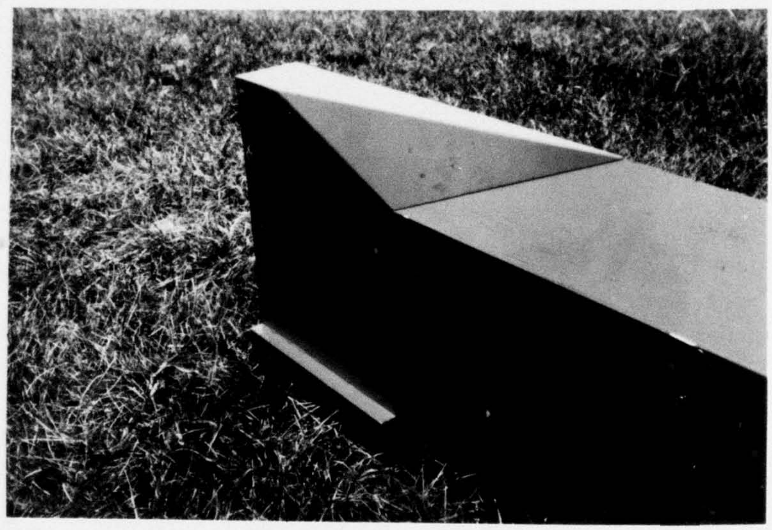


FIGURE 8 - Photograph showing the Detail of the Simplified Sidewall Fairing

TABLE 3

TEST AGENDA FOR MODEL SIDEWALL EXPERIMENTS

RESISTANCE EXPERIMENTS

TEST NO.	SIDEWALL CONFIGURATION
1	45 DEGREE SIDEWALL ALONE, NO FAIRINGS
2	SIDEWALL WITH A FAIRING AT THE TRANSOM
3	SIDEWALL WITH FAIRINGS AT THE TRANSOM AND AT 25% LENGTH FORWARD OF THE TRANSOM
4	SIDEWALL WITH FAIRINGS AT THE TRANSOM, AT 25% LENGTH FORWARD OF THE TRANSOM AND AT 50% LENGTH FORWARD OF THE TRANSOM
5	SIDEWALL WITH FAIRINGS AT THE TRANSOM AND AT 50% LENGTH FORWARD OF THE TRANSOM

PROPULSION EXPERIMENTS

TEST NO.		PROP NO.	PROP LOCATION PORT	STARBOARD	FACILITY CARR. V	CIRCULATING WATER CHANNEL	REMARKS
1		4703	X		X		Drag Experiment for Shortened Sidewall
2		4703	X		X		
3		4704	X		X		
4		4703		X	X		
5		4704		X	X		
6	4703	4704	X	X	X		
7	4704	4703	X	X	X		
8		4703	X		X		Model Keel at Free Surface
2.1		4703	X			X	Repeat of Test 2
3.1		4704	X			X	Repeat of Test 3
4.1		4703		X		X	Repeat of Test 4
6.	4703	4704	X	X		X	Repeat of Test 6
10		4407		X		X	
11		4407	X			X	
12	4407	4704	X	X		X	

It is known from the model experiments and analytical work performed by the ASED that the difference in drag for an l/b = 5.0 craft with and without a fairing at the transom similar to that illustrated in Figure 2 should be about 1 1/2%. To estimate the difference in craft drag for the sidewall configurations of Tests 3, 4, and 5 (See Table 3) the percent difference between each of these tests and Test 2 is determined and divided by the percent difference between Tests 1 and 2. This ratio is then multiplied by 1.015 (i.e. - 1 1/2%) to provide the percent difference in drag that should be applied to the drag values presented in Figure 1.

The total craft drag should increase by about 3.3% for the three fairings per sidewall configurations (Test 4). It was assumed that both the SES with one fairing and the SES with three fairings would run at the same trim and draft. In actuality the craft with three fairings per sidewall should run at a lower trim angle and at slightly less draft, which should reduce the 3.3% figure, but to remain on the conservative side, the 3.3% figure was used. The drag estimate for the final craft configuration is presented in Figure 9.

In attempting to determine the interference drag between the fairings as a function of spacing some interesting, though as yet, not completely explained results were observed. The drag from Test 5 (widely spaced fairings, Figure 7) was greater than the drag from Test 3 (closely spaced fairings, Figure 5). If there was a substantial amount of interference drag one would expect just the opposite trend. A possible explanation

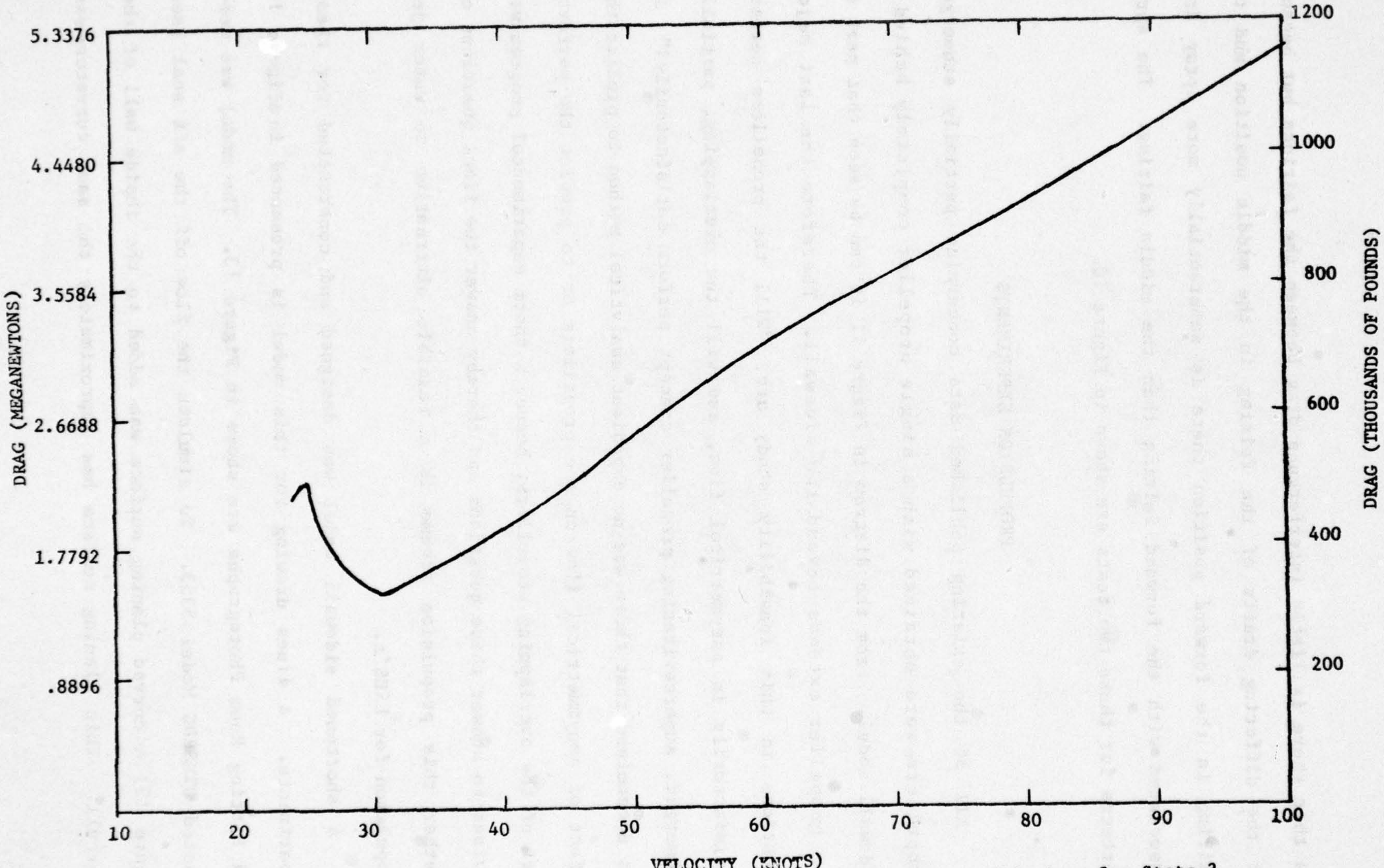


FIGURE 9 - Drag of Final Configuration of a 8,000 Ton Surface Effects Ship in a Sea State 3

is that there is little interference drag between the fairings but because of the differing drafts of the fairing in the middle position and the fairing in the forward position there is substantially more spray drag associated with the forward fairing than the middle fairing. The spray patterns for these two tests are shown in Figure 10.

PROPULSION EXPERIMENTS

All of the existing published data concerning partially submerged propellers were obtained with a single propeller completely behind a sidewall model. From the diagram in Figure 11 it can be seen that part of the propeller extends beyond the sidewall. Therefore the last major questions in this feasibility study are, "Will the propellers perform satisfactorily in assymetrical flow, and will the overlapping, partially submerged, supercavitating propeller concept perform satisfactorily?" It was determined that there was no expedient analytical method to predict the effect of assymmetrical flow on the propellers or to predict the performance of the overlapping propellers, hence, a short experimental program was devised to answer these questions and thereby answer the final questions of whether this propulsion scheme is a feasible alternative to water jet propulsion for LSES's.

A shortened sidewall model was designed and constructed for these experiments. A lines drawing for this model is presented in Figure 12 and Fitting Room Photographs are shown in Figure 13. The model was designated DTNSRDC Model 5353. To simulate the flow off the aft seal (see Figure 13) a curved planing surface was added to the inside wall of the sidehull. This planing surface has approximately the same curvature as

FIGURE 10a - Spray Pattern for Test 3

FIGURE 10b - Spray Pattern for Test 5

FIGURE 10 - Spray Patterns for Tests 3 and 5

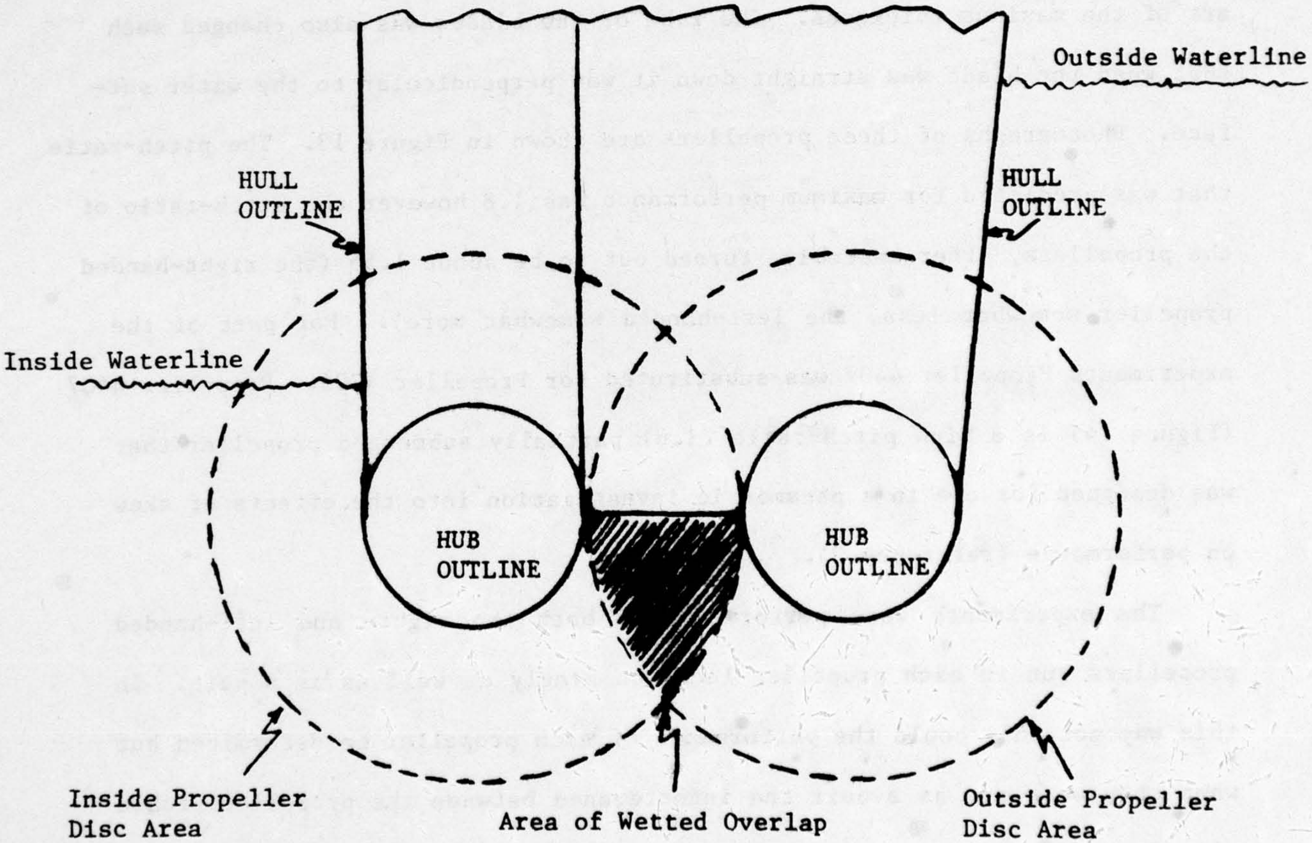


Figure 11 - Sketch Showing Projection of Hull Outline and Propeller Outline

the aft seal and the same height off the baseline as the corresponding values of the $1/b = 5.0$ craft from reference 2.

The propellers used in these experiments were DTNSRDC Propellers 4703 and 4704, a right- and left-handed pair of six bladed propellers. These propellers were assembled using the blades from commercially available two bladed racing propellers with the trailing edges of the blade cut off just aft of the maximum thickness. The rake of the blades was also changed such that when the blade was straight down it was perpendicular to the water surface. Photographs of these propellers are shown in Figure 13. The pitch-ratio that was predicted for maximum performance was 1.8 however the pitch-ratio of the propellers, after assembly, turned out to be about 1.55 (the right-handed propeller somewhat less, the left-handed somewhat more). For part of the experiments Propeller 4407 was substituted for Propeller 4703. Propeller 4407 (Figure 14) is a high pitch ratio (1.8) partially submerged propeller that was designed for use in a parametric investigation into the effects of skew on performance (reference 3).

The experiments were performed with both the right- and left-handed propellers run in each propeller location singly as well as in a pair. In this way not only could the performance of each propeller be determined but when they were run as a pair the interference between the propellers could also be determined. Another possible result is the determination of the optimum rotation for the propellers operating singly and as a pair.

A block gauge was installed on the model so that measurements could also be made of the net body thrust (i.e. that part of the propeller forces that are translated into a longitudinal force on the body). Finally the

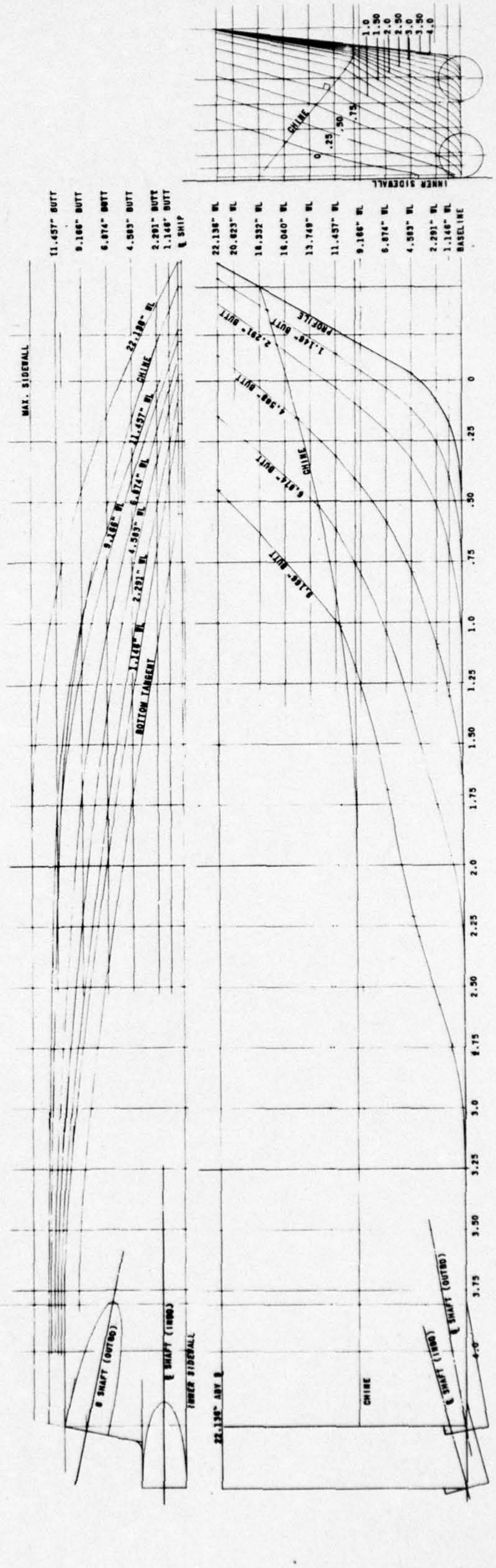


FIGURE 12 - Lines Drawing for Model 5353

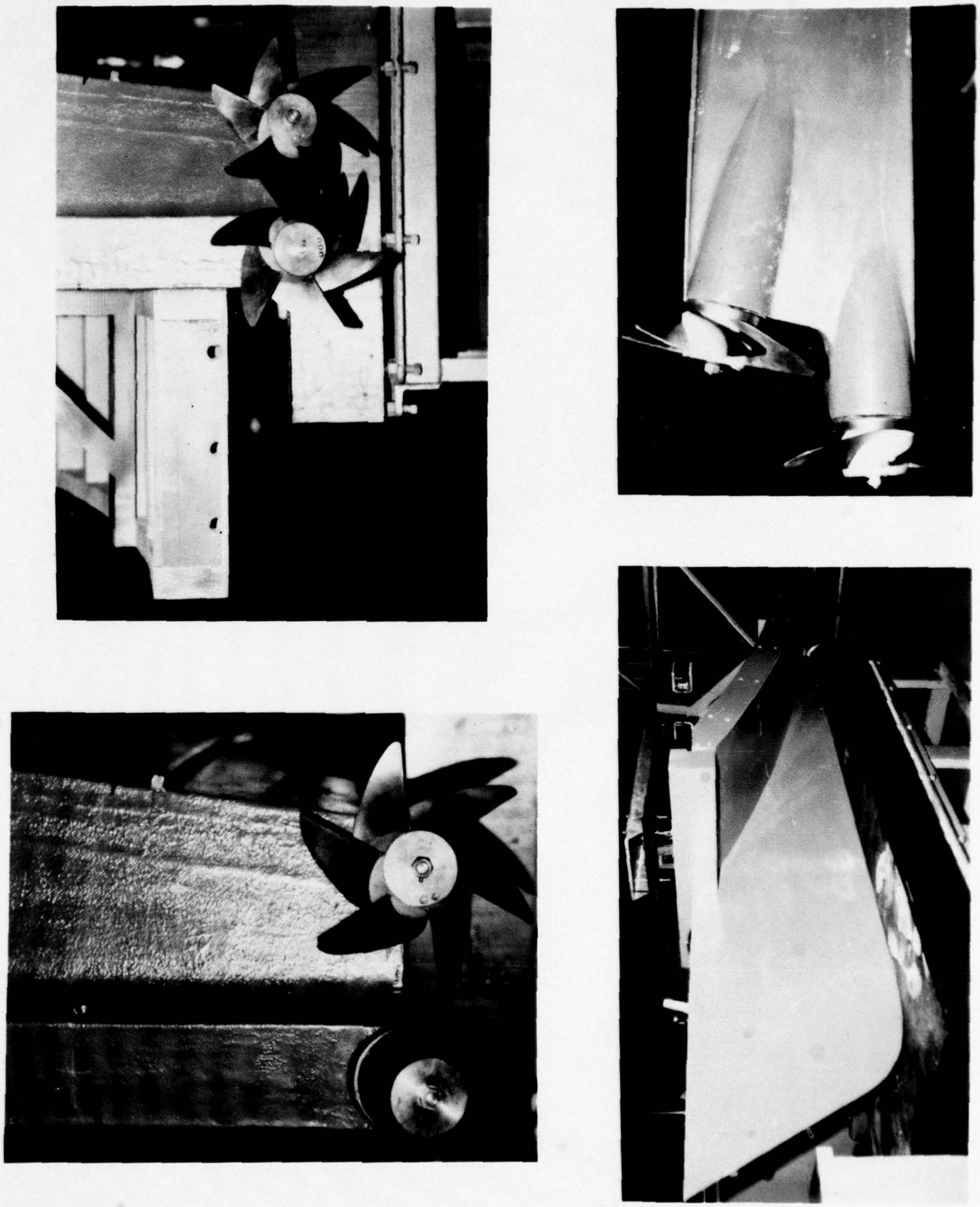
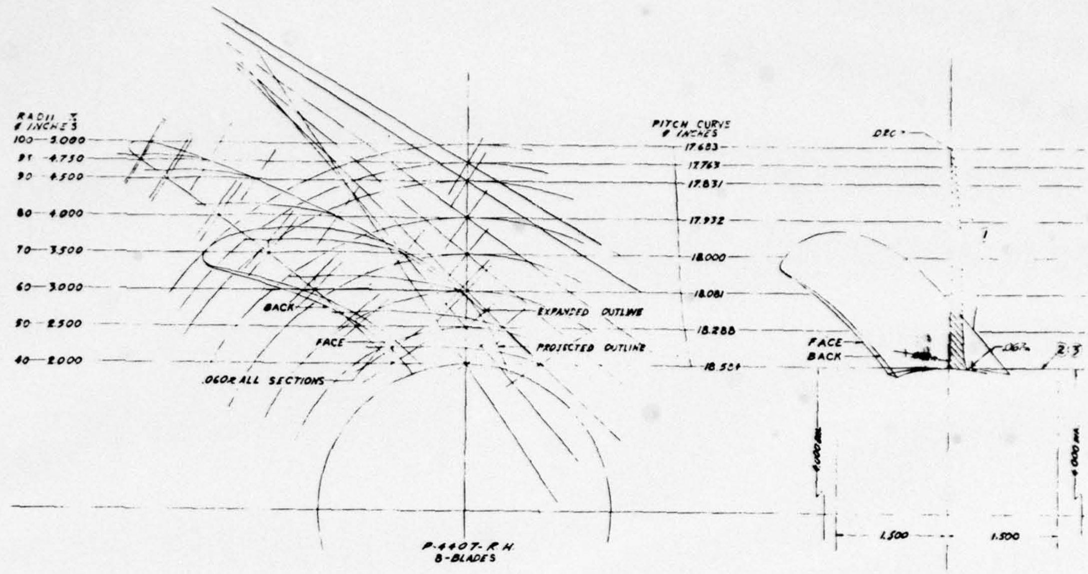


FIGURE 13 - Fitting Room Photographs for Model 5353 Fitted With Propellers 4703 and 4704 and With Curved Planing Surface to Simulate the Aft Seal of a Surface Effects Ship



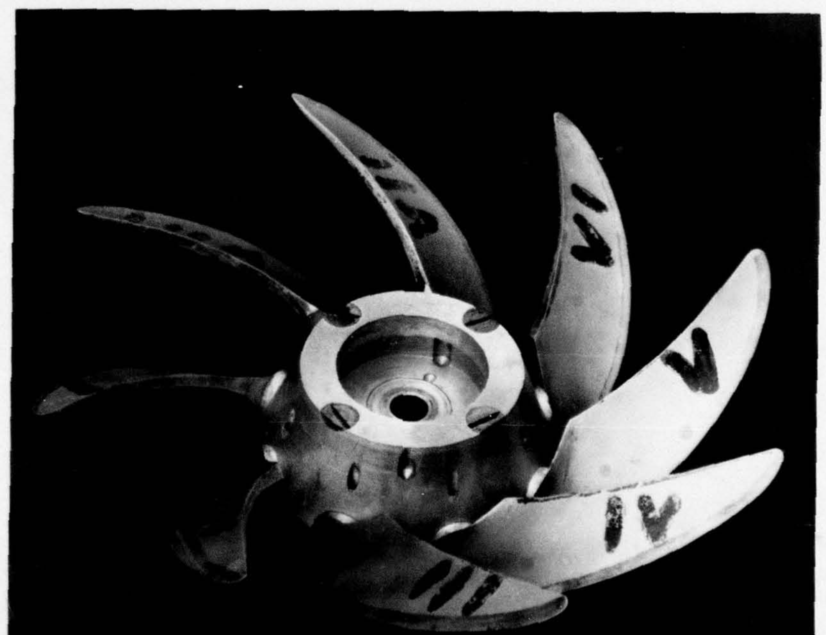


FIGURE 14 - Drawing and Photograph of Propeller 4407

model was run in the Circulating Water Channel (CWC) to observe the flow in the vicinity of the propellers (Figures 15 through 17).

The net body thrust for propellers 4703 and 4704 operating both singly and as a pair and rotating in each direction are presented in Figures 18 and 19. From these figures it is seen that the rotation of the propeller or propellers is probably not the main operating concern from a propulsion point of view though other parameters may change this conclusion. For example, the magnitude of the side forces may be very sensitive to the direction of rotation. The direction of rotation may also be critical for the propellers on the fairings ahead of the transom insofar as keeping the cushion air within the sidewall.

On each of Figures 18 and 19 is a curve denoting the sum of the net body thrust for each of the propellers operating alone. (In Figure 18, Test 2 plus Test 5; in Figure 19, Test 3 plus Test 4.) In each figure this curve is somewhat below the net thrust curve for both propellers operating at the lower RPM's and somewhat higher than the net thrust curve at the higher RPM's. While it may be said that this illustrates that through part of the "J" range there is actually a constructive interference the more important result is that at no time is there a catastrophic destructive interference. Also, the summed curves and the net thrust curves for both propellers operating are sufficiently close together that, with care, predictions of performance can be made from single propeller experiments in preliminary estimates. This conclusion is again illustrated by the K_T curves shown in Figure 20. In this figure the sum of the K_T values for each of the propellers operating alone is shown as a solid line wherein the dashed line is the sum of the K_T values for the propellers operating together.

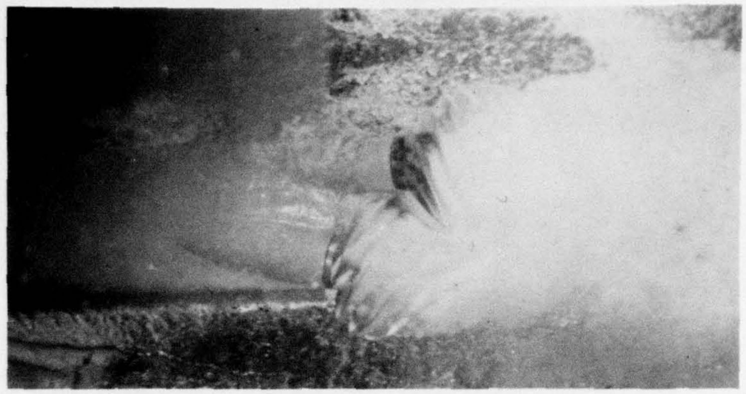


FIGURE 15 - Photograph of Propellers 4407 and 4704 Operating Near Hump (Viewed From Beneath)

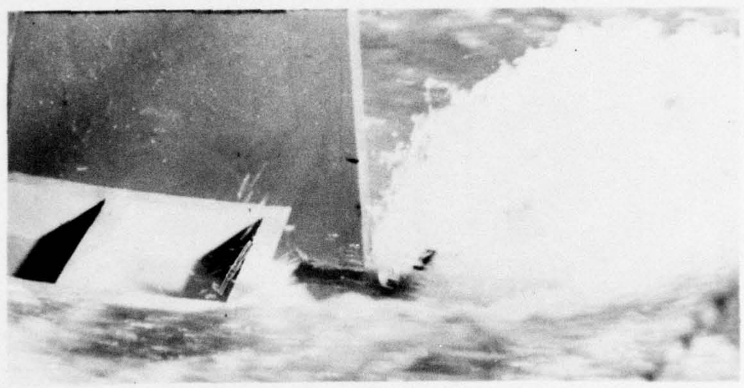


FIGURE 16 - Photograph Showing the Upper Part of Propeller 4407 Above the Water Surface

FIGURE 17 - Photograph Showing the Flow in the Region of the Transom of Model 5353

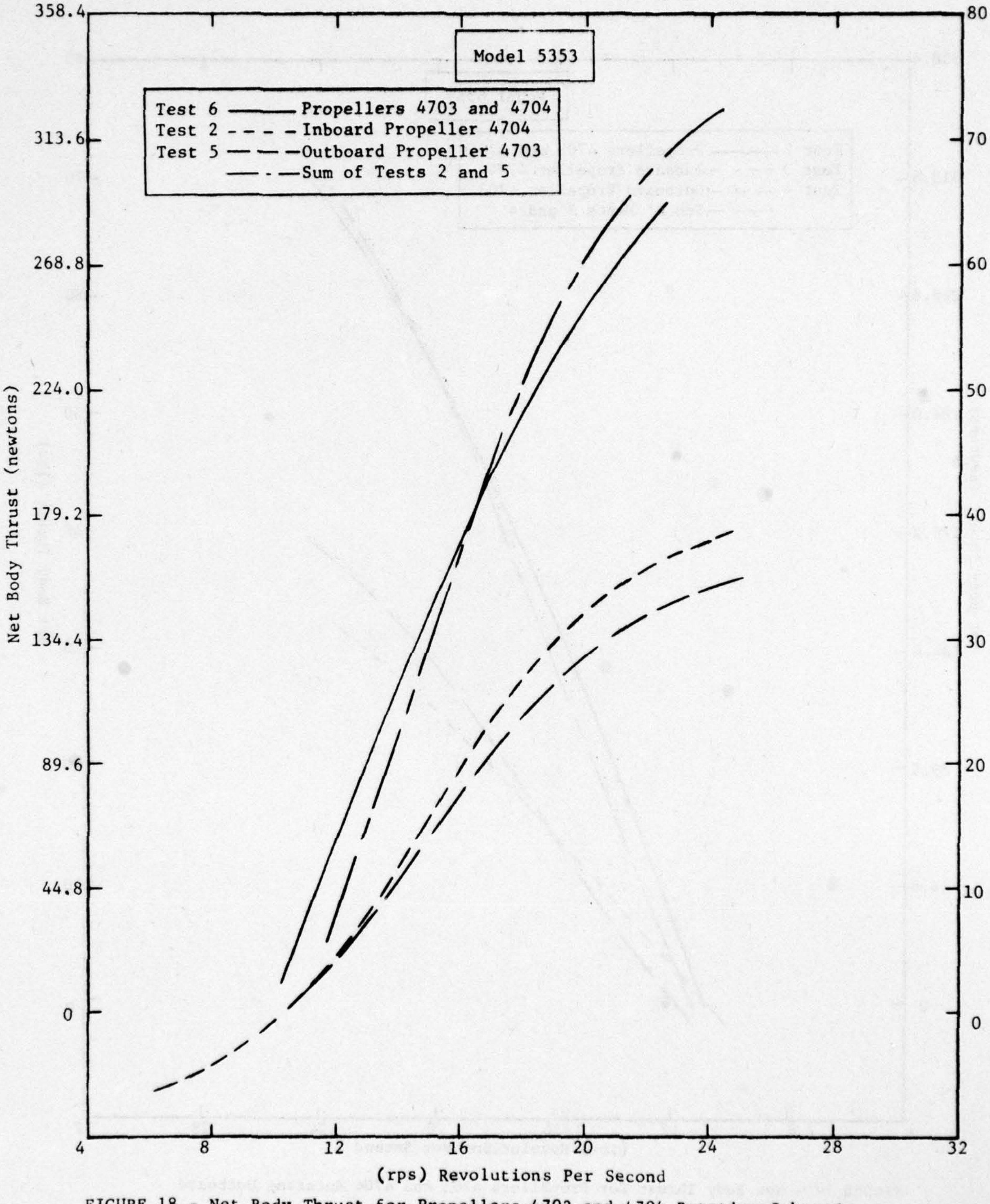


FIGURE 18 - Net Body Thrust for Propellers 4703 and 4704 Rotating Inboard Relative to the Sidewall Centerline

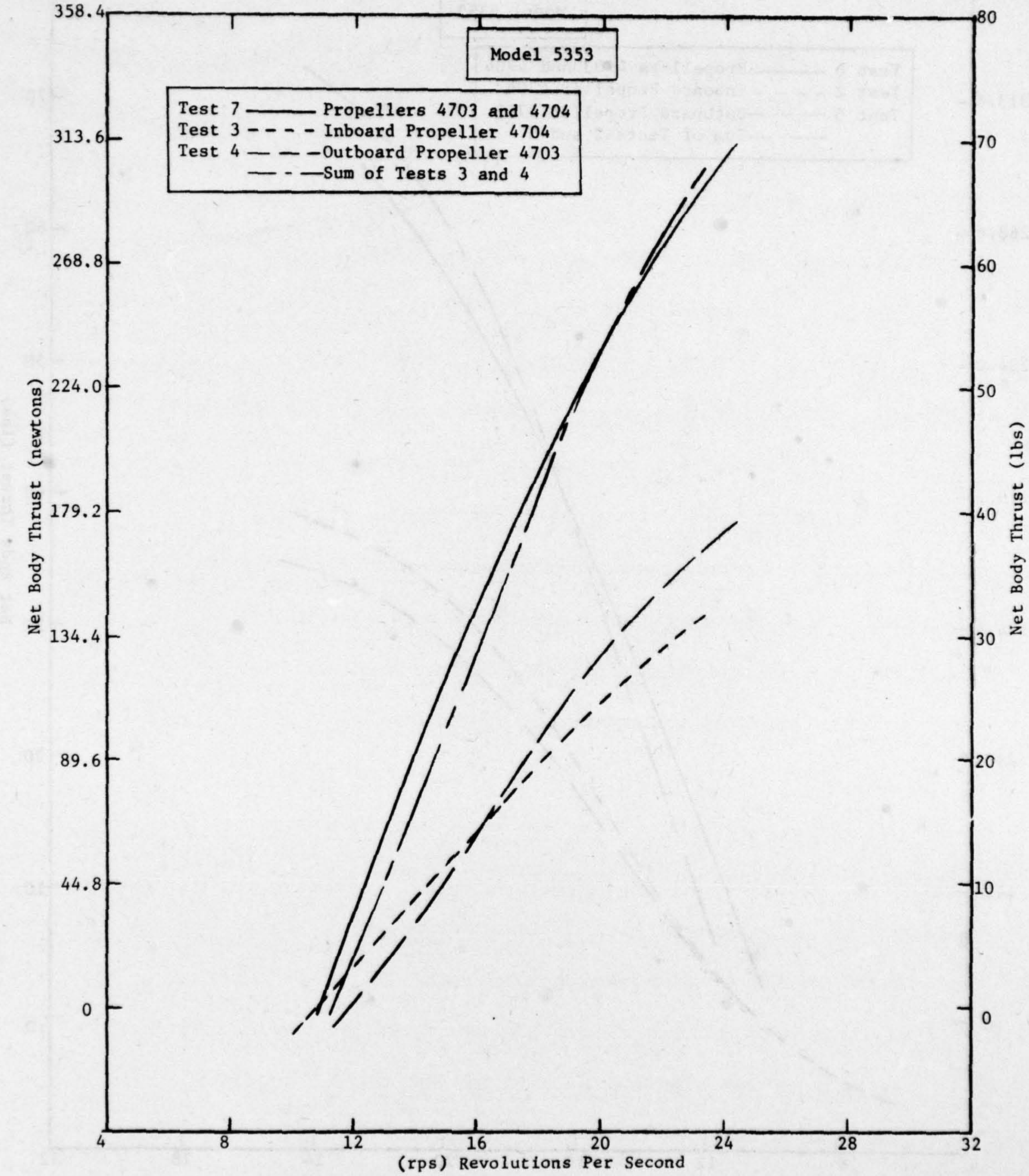


FIGURE 19 - Net Body Thrust for Propellers 4703 and 4704 Rotating Outboard Relative to the Sidewall Centerline

As mentioned previously Propeller 4407 was substituted for Propeller 4703 during part of the experiments. This propeller, even though not designed for this craft, had a pitch-ratio of 1.8, the pitch-ratio predicted to yield maximum performance. The results of the experiments with Propeller 4407 operating both singly and in combination with Propeller 4704 are presented in Figure 21. From this figure it can be seen that the propeller performance is not drastically changed when operating as an overlapping pair. The peak efficiencies for these experiments are in the neighborhood of 60%. This is somewhat less than the peak efficiencies reported in reference 3 but is about what was expected from past experience at the Center due to the change in the propeller submergence. The higher efficiencies in reference 3 were obtained at a submergence of 30% whereas the effective propeller submergence in these experiments was about 70%.

The results of these experiments and the observations made in the Circlating Water Channel have clearly shown that a propulsion system similar to the one discussed is feasible. The experiments have contributed to the knowledge of the operation of partially submerged propellers in such a way that the engineer can now have a positive basis to begin more detailed design(s).

The principal results from these experiments were:

(1) The propellers performed well both singly and as a pair.

(2) The propellers performed well rotating in either direction.

(3) From a propulsion viewpoint there is not clear optimum rotation for the propellers.

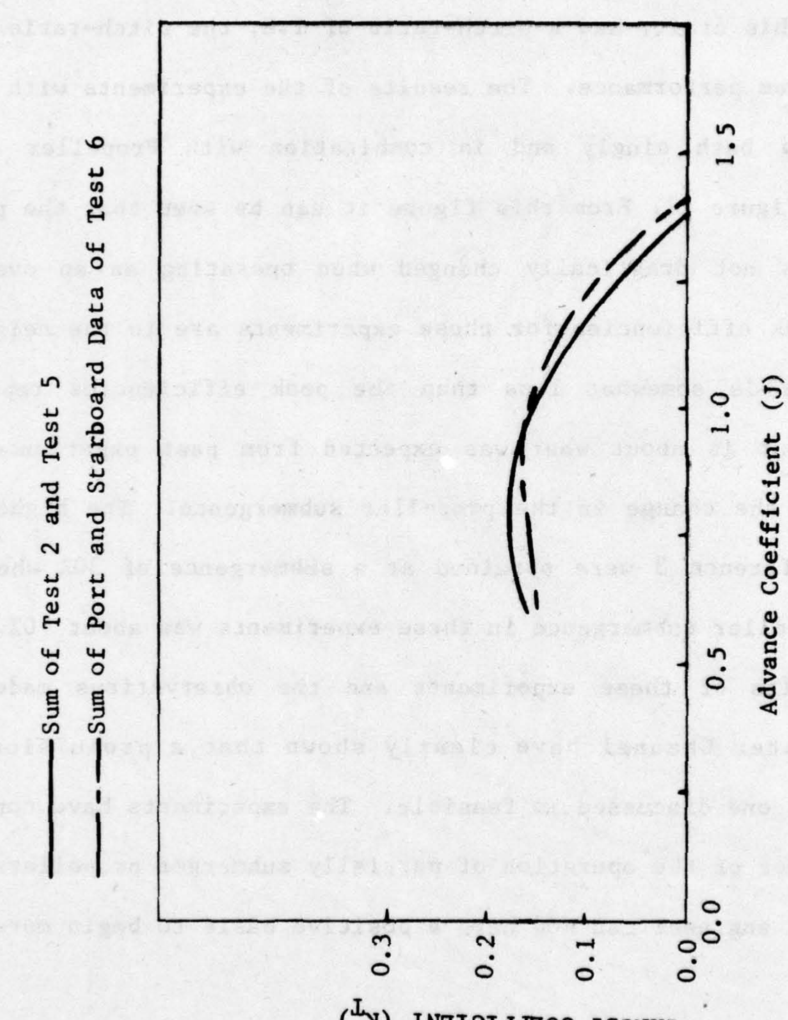


FIGURE 20 - Total K_T Curves for Test 6 and Tests 2 and 5

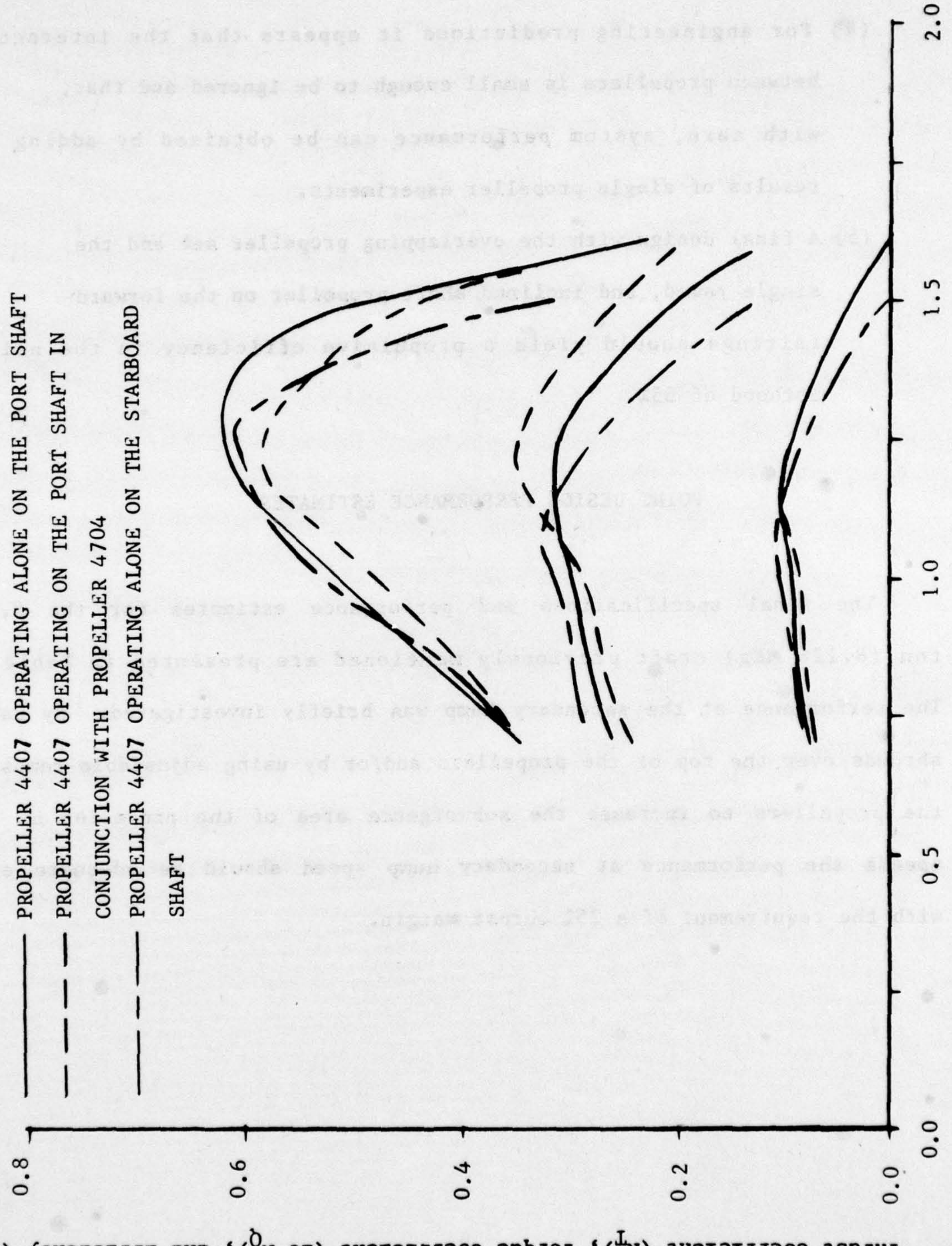


FIGURE 21 - Performance Characteristics for Propeller 4407 for Three Different Operating Conditions

(4) For engineering predictions it appears that the interaction between propellers is small enough to be ignored and that, with care, system performance can be obtained by adding the results of single propeller experiments.

(5) A final design with the overlapping propeller set and the single yawed, and inclined shaft propeller on the forward fairings should yield a propulsive efficiency in the neighborhood of 65%.

POINT DESIGN PERFORMANCE ESTIMATES

The final specifications and performance estimates for the 8,000 ton (8.128 MKg) craft previously mentioned are presented in Table 4. The performance at the secondary hump was briefly investigated. By using shrouds over the top of the propellers and/or by using adjustable ramps at the propellers to increase the submergence area of the propeller at low speeds the performance at secondary hump speed should be adequate even with the requirement of a 25% thrust margin.

TABLE 4

FINAL SPECIFICATIONS AND PERFORMANCE ESTIMATES

FOR

AN 8,000 TON (8.128 MKg) SURFACE EFFECTS SHIP

Design speed	60 knots
Design sea state	3
Cushion length-beam ratio	5.0
Drag at design speed	705,500 pounds (3.138 MN)
Propellers per sidewall	4*
Thrust per propeller	88,180 pounds (393.2 kN)
Propeller diameter	12.0 feet (3.66 m)
Shaft power per propeller	24,940 SHP (18.5978 MW)
Propeller RPM	403**
Propeller efficiency	0.651

* It is probable that all 4 propellers can be fixed pitch.

** From incomplete experimental data a final design propeller would probably have a higher RPM thereby reducing the necessary gearbox ratio but at this time the magnitude of the change in RPM is not known. If the necessary machinery constraints can be met with 403 RPM propeller, then raising the RPM would only ease the mechanical and structural difficulties.

For others required to provide a point design for ANVCE and other similar programs, where one propulsion system candidate consists of partially submerged propellers the performance may, for the time being, be calculated using the values presented in Table 5. For a design speed of 60 knots these values will produce the curve shown in Figure 22. For other speeds the trends will be similar but the magnitudes will be different.***

*** Clearly as additional studies and series of data become available, other parameters will be considered and used.

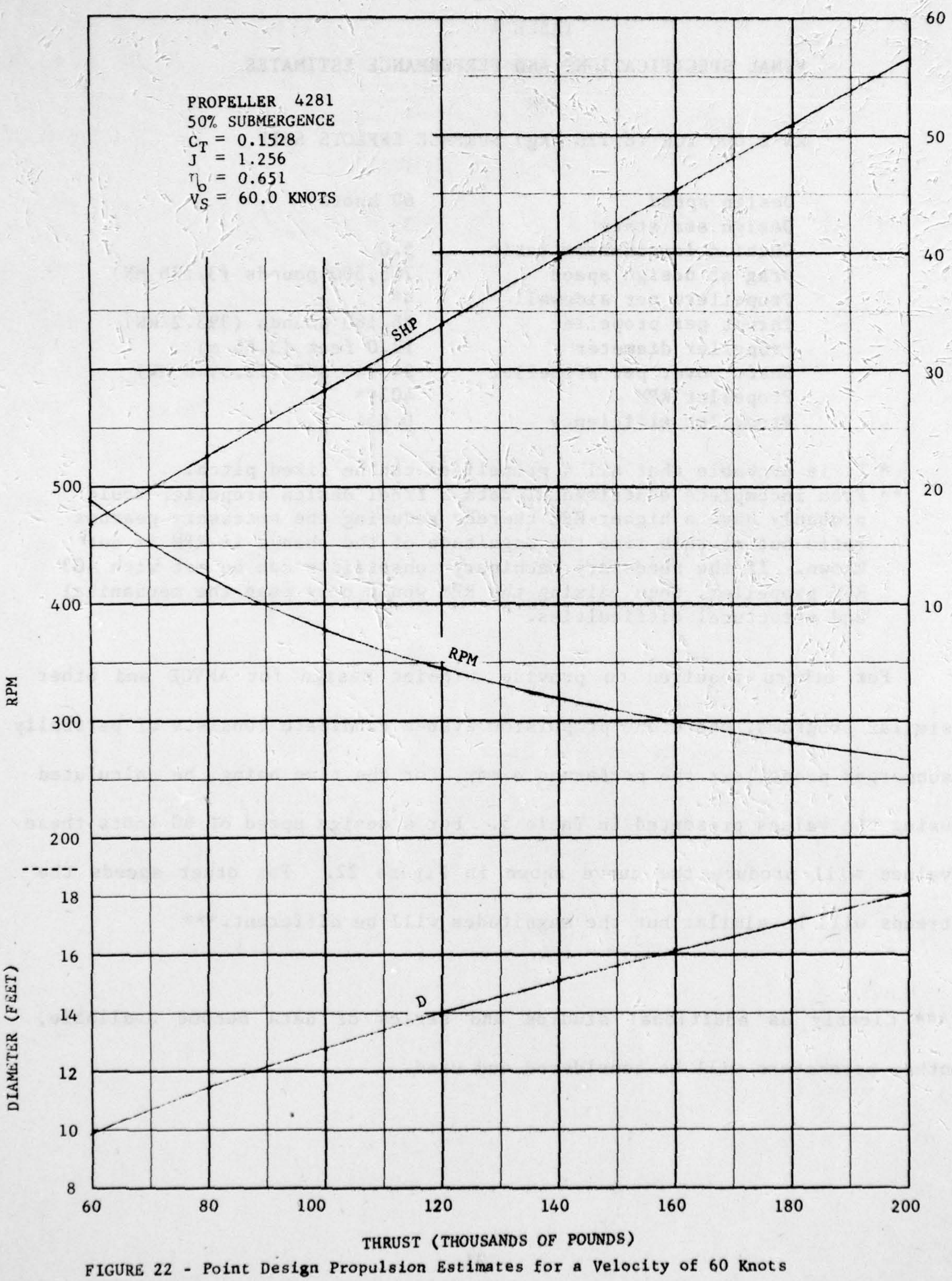


FIGURE 22 - Point Design Propulsion Estimates for a Velocity of 60 Knots

TABLE 5

POINT DESIGN PROPULSION PARAMETERS

$C_T = 0.1528$* J = 1.256 $h_O = 0.651$

* C_T here is based on 50% submergence

RECOMMENDATIONS

In the beginning of the paper it was noted that the purpose of this work was to determine the feasibility of propelling large surface effects ships with widely spaced, partially submerged, supercavitating propellers. The feasibility has been shown, but this is only a first step in producing an operational craft with this type of propulsion.

For a near term experimental effort Model 5353 should be equipped with shrouds or "eyebrows" over the propellers and with no other modifications to either the model or the propellers the low speed performance should be determined. The information determined from this series of experiments could then be used to increase the operational knowledge for partially submerged propellers, using the present work as a basis for detailed design efforts for propeller driven LSES.

A far term effort should consist of simultaneous, coordinated work in the area of craft resistance and propulsion system design. The craft resistance should include optimization of the:

(1) seal type and placement,

(2) trim,

(3) sidewall fairing placement and

(4) longitudinal center of gravity.

The propulsion system design program should include optimizations of the:

(1) propellers,

(2) shaft angles and,

(3) fairing design.

Additionally there is a need for a parametric investigation of the performance of partially submerged propellers in off-design conditions including the hump or take-off region. This would aid greatly in the ability of the engineer to quickly produce performance estimates for almost any arbitrary craft over its entire speed range. Hopefully, this investigation would include the effects of shrouds and ramps on the performance and possibly lead to a method where the effects of each element could be determined.

APPENDIX A

ILLUSTRATION OF PROCEDURE FOR OBTAINING PROPULSION ESTIMATES

All propeller performance predictions performed for this report were made using existing data at the Center for Propeller 4281. An illustration of the procedure for obtaining propulsion estimates using Propeller 4281 is furnished in the following example.

Sample Calculation

Find the optimum rpm and pitch ratio for the following conditions:

Diameter = 31.2 feet

Thrust = 300,000

Speed = 60 knots

(1-w) and (1-t) = 1.0

The thrust coefficient, C_T which is independent of rpm, is

$$C_T = \frac{T}{\frac{\rho}{2} A_s V^2}$$

where, for a semi-submerged propelled, $A_s = \frac{1}{2} \left(\frac{\pi D^2}{4}\right)$

$$C_T = \frac{300{,}000}{\frac{1.9905}{2} \; \frac{1}{2} \; \frac{\pi(31.2)^2}{4} \quad (60 \times 1.6878)}$$

$= 0.077$

$\sqrt{C_T} = 0.278$

Using Figure A-1, and the $\sqrt{C_T}$ calculated above, we find the intersection of this constant $\sqrt{C_T}$ with the curve of maximum efficiency for a constant C_T. This point gives the value of J from which the optimum rpm for a given diameter can be calculated. In this example the calculated $\sqrt{C_T}$ = 0.278. This $\sqrt{C_T}$ intersects the curve of maximum efficiency for a constant

C_T at J = 1.460. Using $J = \dfrac{V}{nD}$, the optimum rpm is calculated to be 133 rpm.

Based on test results and photographs, the area of full ventilation is designated in Figure A-1. To ascertain if the propeller in this example is based on fully ventilated data, the operating point for the propeller is checked against the fully vented operating area of Figure A-1. This propeller is not fully ventilated, therefore the data should be used with caution. The operating conditions for the propeller are:

$$P/D = 1.75$$

$$J = 1.460$$

$$\eta = 0.702$$

The power required can be determined from

$$C_P = \frac{C_T}{\eta}; \quad C_P = \frac{0.077}{0.702} = 0.110$$

therefore SHP = 78,700.

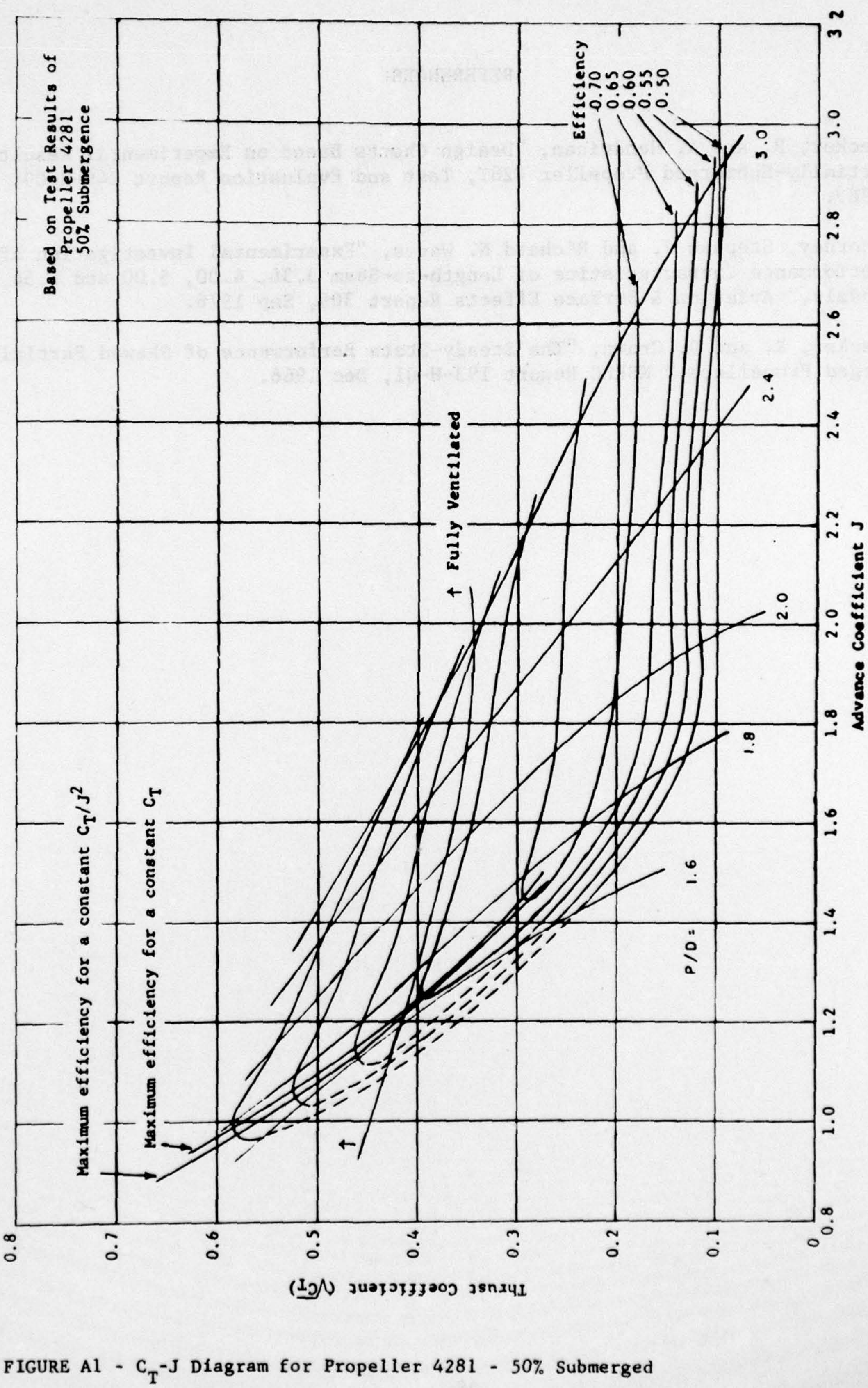


FIGURE A1 - C_T-J Diagram for Propeller 4281 - 50% Submerged

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3. Hecker, R. and D. Crown, "The Steady-State Performance of Skewed Partially-Submerged Propellers," NSRDC Report 193-H-01, Dec 1966.

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